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Meteosat-8 AMVs over the Indian Ocean

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Abstract

Meteosat-8 is scheduled to replace Meteosat-7 as the prime IODC satellite from February 2017. In this report we assess the quality of Meteosat-8 AMVs over the Indian Ocean and evaluate their impact on global NWP forecasts. Collocation with Meteosat-10 shows the Meteosat-8 AMVs are very similar in quality over the same geographic area. At low level the IR and visible channel winds from Meteosat-8 have larger O-B departures globally because of the greater coverage over land. Nevertheless, Meteosat-8 departures are clearly smaller than Meteosat-7, especially at high level. Replacing Meteosat-7 with Meteosat-8 results in 2000 additional AMVs assimilated and a small improvement in the observations fit to the background forecast. Versus a 'no IODC AMV' baseline the impact of Meteosat-8 on forecast RMS errors is found to be small but generally beneficial. Statistically significant error reductions are seen for tropical winds at 850 hPa at all lead times versus analyses. At 250 hPa wind errors are reduced in the tropics at short-range and in the northern hemisphere at longer lead times. Southern hemisphere 500 hPa geopotential height errors are reduced versus independent ECMWF analyses (but not significantly). However, both Meteosat-7 and Meteosat-8 lead to an increase in forecast errors for winds at 250 hPa in the southern hemisphere as the AMV assimilation acts to slow the jet stream.

The overall forecast impact of Meteosat-8 is encouraging considering the extensive overlap with Meteosat-10. It is recommended that Meteosat-8 winds replace Meteosat-7 in operations from February 2017 to ensure continuity in AMV coverage over the Indian Ocean.

1. Introduction

Meteosat-8 has been drifted in to its new position at 41.5°E and is scheduled to replace Meteosat-7 as the prime Indian Ocean Data Coverage (IODC) satellite on 1 February 2017. Meteosat-8 meteorological products, including AMVs and clear-sky radiances, have been disseminated in parallel since the end of October 2016. The parallel data period is scheduled to run until the end March 2017 after which Meteosat-7 will be moved to a graveyard orbit (expected early April 2017). The purpose of this report is to

evaluate the impact of replacing Meteosat-7 AMVs with Meteosat-8 AMVs in preparation for a planned operational switchover in February 2017.

2. Indian Ocean AMVs: availability and coverage

AMVs are generated from several satellites covering at least part of the Indian Ocean region. These are briefly summarised in Table 1. Meteosat-8 is the first of the Meteosat Second Generation (MSG) satellite series and carries the Spinning Enhanced Visible and Infrared Imager (SEVIRI) imager which has 12 spectral channels, a significant advance on the 3 channels on Meteosat First Generation (MFG). Meteosat-8 AMVs are generated from the same set of 7 channels as for Meteosat-10 located at 0°E and have the benefit of being generated hourly as opposed to 3-hourly for Meteosat-7. Spatial resolutions are also improved from 5-km to 3-km for the IR, WV and visible 0.7/0.8 μm channels, whilst the high resolution visible (HRVIS) has a resolution of 1-km at sub-satellite point (SSP).

Other satellites in the region include INSAT-3D operated by India and FY-2E/G operated by China. INSAT-3D AMVs have good temporal resolution (hourly) but the WV winds have low spatial resolution and are from a mixture of clear and cloudy targets. For the November-December 2016 period considered in this study, INSAT-3D reliability is poor with patchy temporal coverage and numerous dropouts. The FY-2E/G satellites only produce AMVs every 6 hours (each offset by 3 hours) and at the time of study only FY-2G is producing sensible wind data.

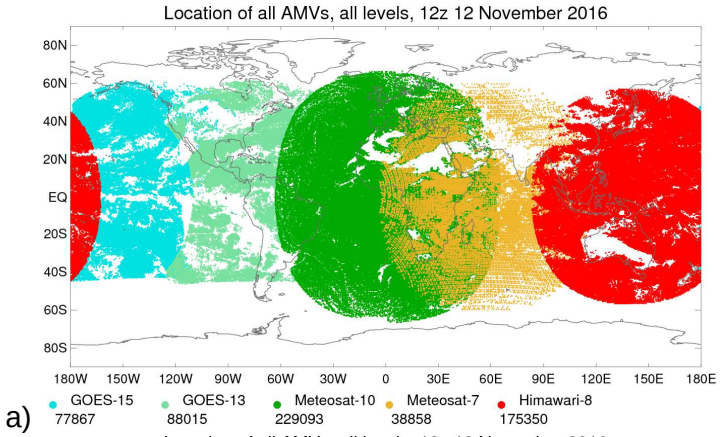
Satellite	Producer	Location	AMV Channels	Frequency	Resolution SSP	Target
Met-7	EUMETSAT	57.5°E	IR Visible WV	3-hours	5-km	16x16 (Vis, WV) 32x32 (IR,CSWV)
Met-8	EUMETSAT	41.5°E	IR 10.8 µm Visible 0.8 µm HRVIS WV 6.2/7.3 µm CSWV 6.2/7.3 µm	1-hour	3-km 1-km (HRVIS)	24x24 32x32 (HRVIS)
INSAT-3D	IMD/ISRO	82°E	IR IR 3.8 µm Visible Mixed WV	1-hour	8-km (WV) 4-km (IR) 1-km (Vis, IR 3.8 µm)	20x20 (8 images)
FY-2G	CMA	105°E	IR WV CSWV	6-hours (0/6/12/18z)	5-km (IR) 1.25-km (Vis)	1st tracking 32x32 2nd tracking 16x16
FY-2E	CMA	86.5°E	IR WV CSWV	6-hours (3/9/15/21z)	5-km (IR) 1.25-km (Vis)	1st tracking 32x32 2nd tracking 16x16

Table 1: Status of AMVs over the Indian Ocean region.

The spatial coverage provided by the Indian Ocean satellites (excluding FY-2E) is presented in Figure 1. It is clear that Meteosat-8 has much denser coverage thanks to the increased number of channels and higher temporal frequency. Meteosat-8 at 41.5°E is not located as far east as Meteosat-7 and therefore overlaps with Meteosat-10 to a greater extent. As a result, one potential concern would be the opening of coverage gaps in the mid-latitudes between Meteosat-8 and Himwari-8. However Meteosat-8 AMVs are generated over a larger 'disc' than Meteosat-7 so the gaps around 90-110°E are not that different from the case with Meteosat-7. LeoGeo winds and EUMETSAT Metop-A/B polar winds provide coverage polewards of around 50° and 40° latitude respectively (not shown here) and so the mid-latitude gaps are easily filled by other data sets. A major limitation in the current use of Meteosat-7 is that all IR winds above 700 hPa height are rejected south of 20°S because of the severe biases observed in the monitoring statistics. Meteosat-8 replacing Meteosat-7 will therefore improve AMV coverage in the southern hemisphere.

INSAT-3D coverage is limited to a smaller square shape and notice the inclusion of clear-sky targets from the mixed WV channel over North India. FY-2G also covers a smaller circular area. Both satellites provide some coverage in the Meteosat-8/Himawari-8 gaps.

In the remainder of this report we consider only AMVs from Meteosat-8 as a replacement for Meteosat-7.



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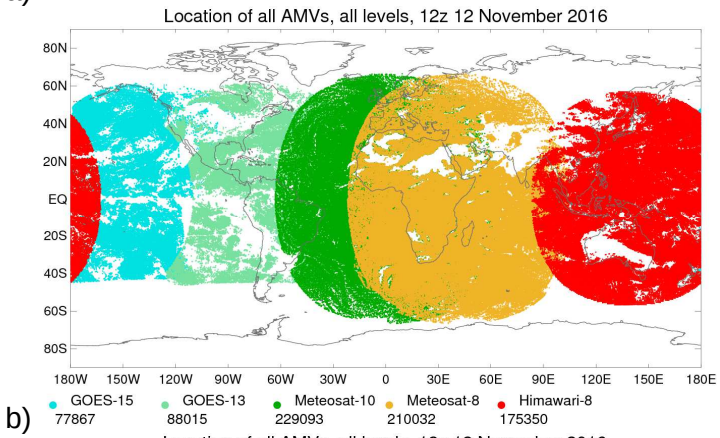

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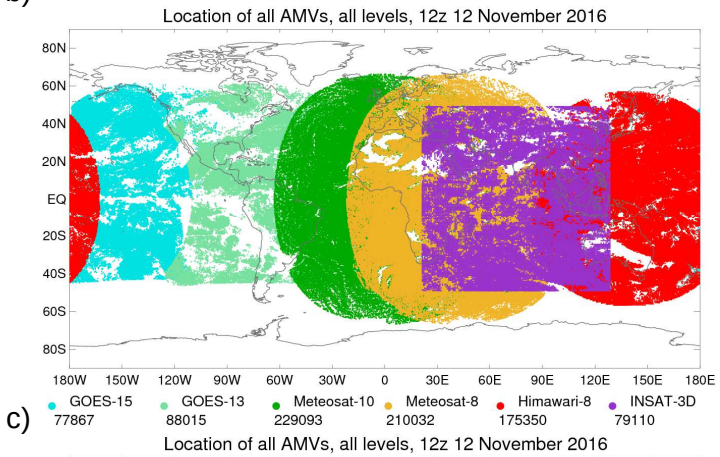

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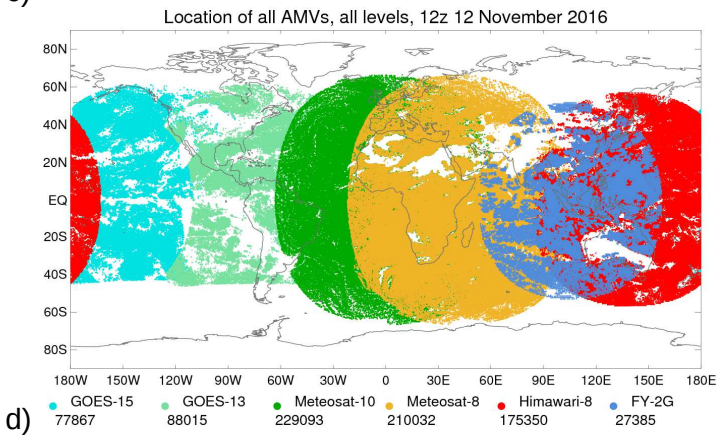


d)

Figure 1: AMV coverage of the geostationary ring of satellites (Meteosat-10, Himawar-8, GOES-13/15) for those channels assimilated in operations, plus: a) Meteosat-7, b) Meteosat-8, c) INSAT-3D (all channels), d) FY-2G (IR/WV only).

3. O-B statistics

In this section we evaluate the quality of Meteosat-8 AMVs primarily by comparing to Meteosat-10.

3.1. O-B speed bias

Observations minus background (O-B) speed bias statistics for Meteosat-7/8/10 are presented in Table 2 and Table 3. These statistics are global, and as the satellites cover different geographic areas are not directly comparable, but give a ball-park figure as to how the AMVs compare.

The low level IR and visible channel winds from Meteosat-8 and Meteosat-10 compare very well in the southern hemisphere (SH) and tropics. In the northern hemisphere (NH) Meteosat-8 winds have standard deviation speed bias values up to 2x larger than Meteosat-10. The IR channel also has a larger positive bias in the NH. The biases for Meteosat-8 in the NH remain smaller than Meteosat-7 however, which suggests that the degraded statistics here relative to Meteosat-10 could be due to differences in the geographic area covered.

The IR and cloudy WV 7.3 μm channels for Meteosat-8/10 have broadly similar biases at high level across all latitude bands. Both exhibit a negative speed bias in the NH (up to -2 m/s for Meteosat-8 IR) and SH (around -1 m/s for IR). Meteosat-7 has a very large negative bias for the IR channel in the extra-tropics (around -4 m/s) and higher standard deviation. It is clear that the MSG AMVs are superior in quality to MFG at high level.

Satellite	Channels	NH			TR			SH		
		Number	Mean m/s	Stdv m/s	Number	Mean m/s	Stdv m/s	Number	Mean m/s	Stdv m/s
Met-10	IR	341108	0.47	3.96	959839	0.35	2.45	648133	0.45	3.74
	WV7.3									
	VIS	164562	0.17	2.58	616916	0.24	1.81	465453	0.04	2.49
	HRVIS	492083	0.35	3.17	1772082	0.25	1.78	1662902	0.25	2.56
Met-8	IR	63495	1.96	7.90	758449	0.59	2.58	741703	0.22	3.27
	WV7.3									
	VIS	33030	0.39	5.08	516085	0.45	1.89	505211	-0.11	2.34
	HRVIS	148980	1.43	5.28	1992099	0.32	1.67	1935267	0.20	2.35
Met-7	IR	2777	2.25	9.02	86441	0.77	2.95	80340	0.00	2.39
	WV									
	VIS	1688	1.50	5.32	165560	0.62	2.28	129416	0.34	2.52

Table 2: O-B speed bias statistics for low level AMVs in November 2016. Winds are filtered for QI2 > 80 and heights below 700 hPa. NH = northern hemisphere (90°N-20°N), SH = southern hemisphere (90°S-20°S), TR= tropics (20°N-20°S).

Satellite	Channels	NH			TR			SH		
		Number	Mean m/s	Stdv m/s	Number	Mean m/s	Stdv m/s	Number	Mean m/s	Stdv m/s
Met-10	IR	694236	-1.60	5.76	1182789	0.17	4.66	701213	-1.07	5.96
	WV7.3	805687	-0.65	5.79	1499498	0.70	4.83	816800	-0.07	5.97
	VIS									
	HRVIS									
Met-8	IR	504512	-2.04	5.99	1112094	0.03	4.33	563918	-1.18	6.05
	WV7.3	585264	-1.18	5.91	1414356	0.54	4.49	659673	-0.07	5.90
	VIS									
	HRVIS									
Met-7	IR	52412	-4.11	6.70	185995	-0.11	3.92	65297	-3.69	7.31
	WV	214468	-1.86	7.01	682854	1.24	4.54	255222	-1.15	7.52
	VIS									

Table 3: Same caption as for Table 2, but for high level winds above 400 hPa height

3.2. Zonal and map plots

Zonal O-B plots for IR, WV 7.3 µm, and visible 0.8 µm channel AMVs are shown in Figure 2, Figure 3, and Figure 4 respectively. For IR channel AMVs Meteosat-8 has a mean positive speed bias and increased vector difference located around 15-30°N, stretching from near the surface up to around 300 hPa height. This bias is more pronounced compared to Meteosat-10, especially for AMVs at low and mid-level. Maps of low level (Figure 5) and mid level O-B show this difference is from the change in geographic coverage as large biases are seen for Meteosat-8 over the Arabian Sea and North India which are not covered by Meteosat-10. Figure 2 and Figure 4 also show larger mean vector differences (MVD) for Meteosat-8 more generally at low level in the NH. Figure 5 and Figure 6 again show this is due to the position of Meteosat-8 further east, which results in greater coverage over land where low level AMV quality is generally worse.

For the IR channel at low level we find a lower density of observations in the Atlantic and a higher density in Indian Ocean compared to Meteosat-10 (Figure 5). The HRVIS channel also has a very different distribution of data over the ocean, as Meteosat-8 has a very high density of data east of 40°E (not shown).

In general the maps for Meteosat-8 and Meteosat-10 look similar when compared over the same geographic area.

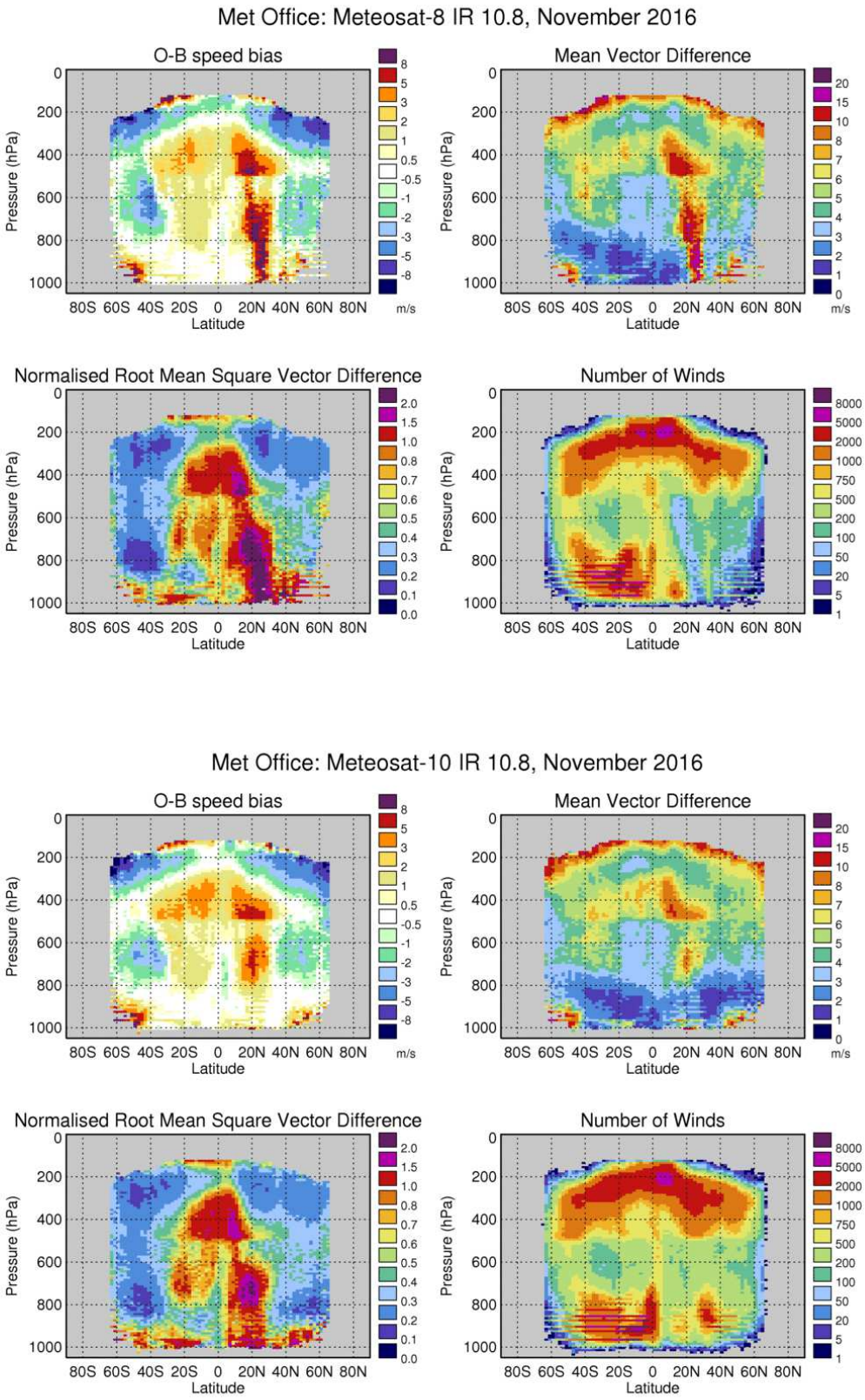


Figure 2: IR10.8 channel monitoring plots as a function of latitude and pressure for Meteosat-8 (top) and Meteosat-10 (bottom): O-B speed bias, MVD, normalised MVD, and number of AMVs.

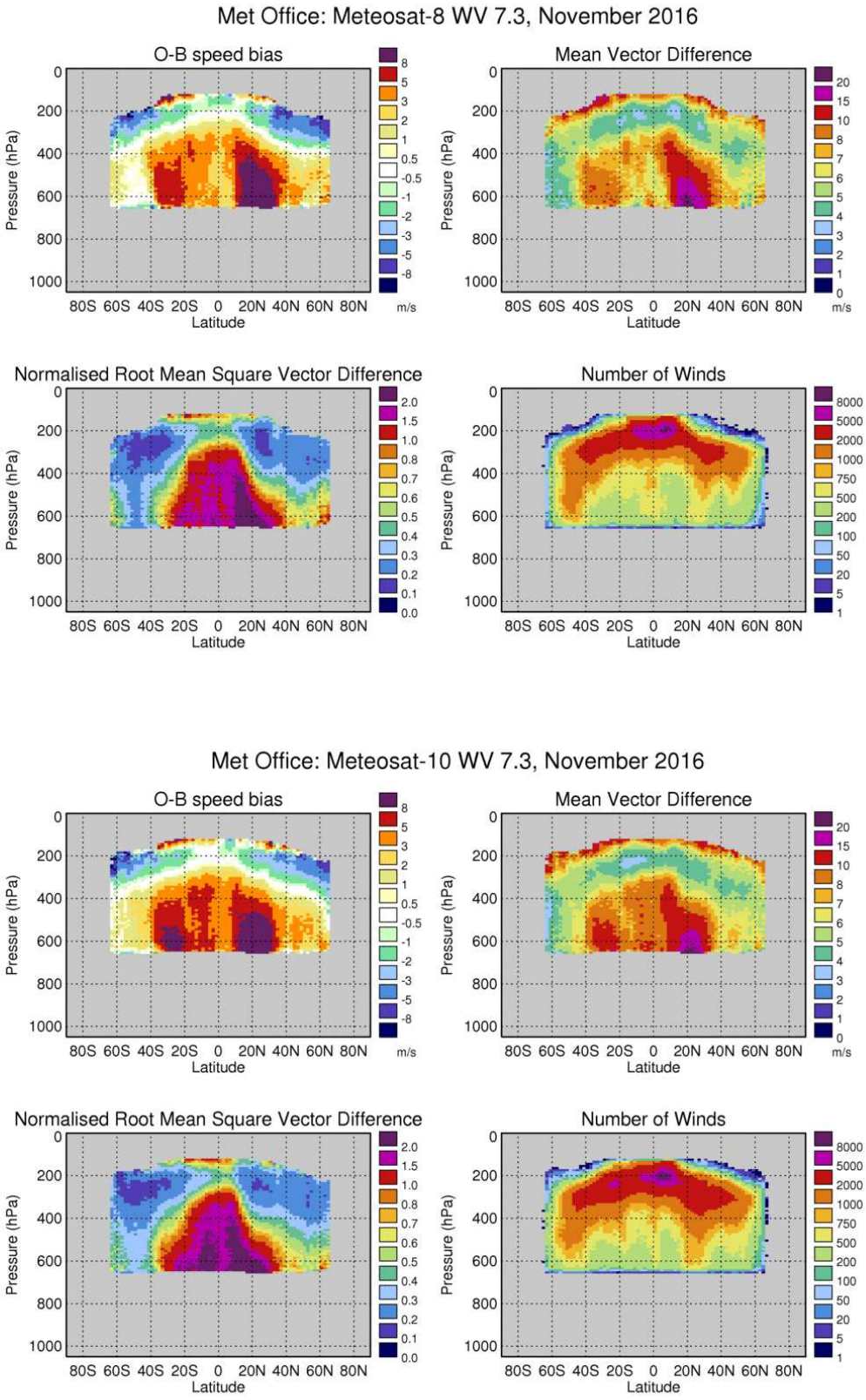


Figure 3: As Figure 2 but for WV7.3 channel AMVs.

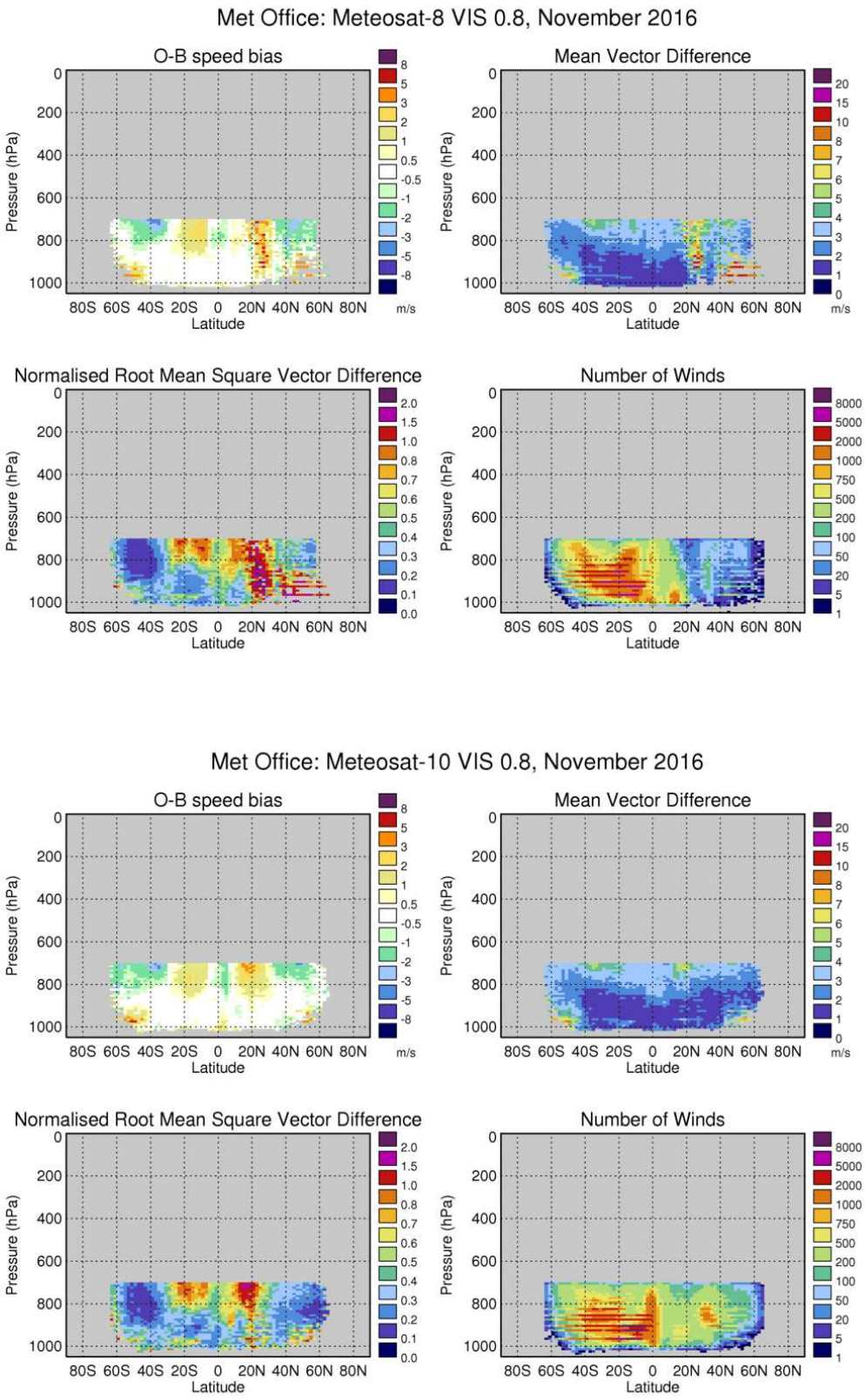


Figure 4: As Figure 2 but for visible 0.8 channel AMVs.

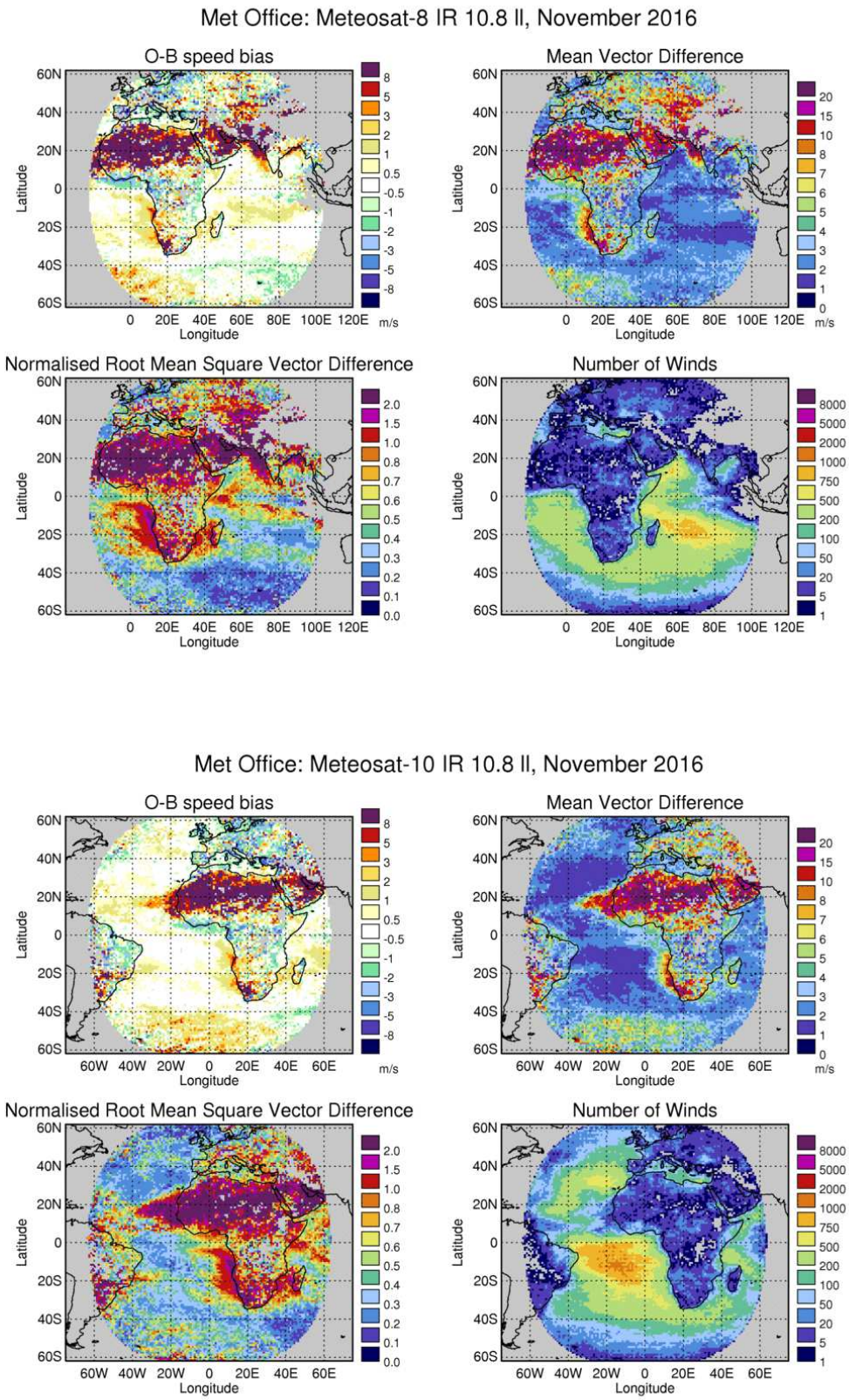


Figure 5: IR10.8 channel map plots for Meteosat-8 (top) and Meteosat-10 (bottom): O-B speed bias, MVD, normalised MVD, and number of AMVs.

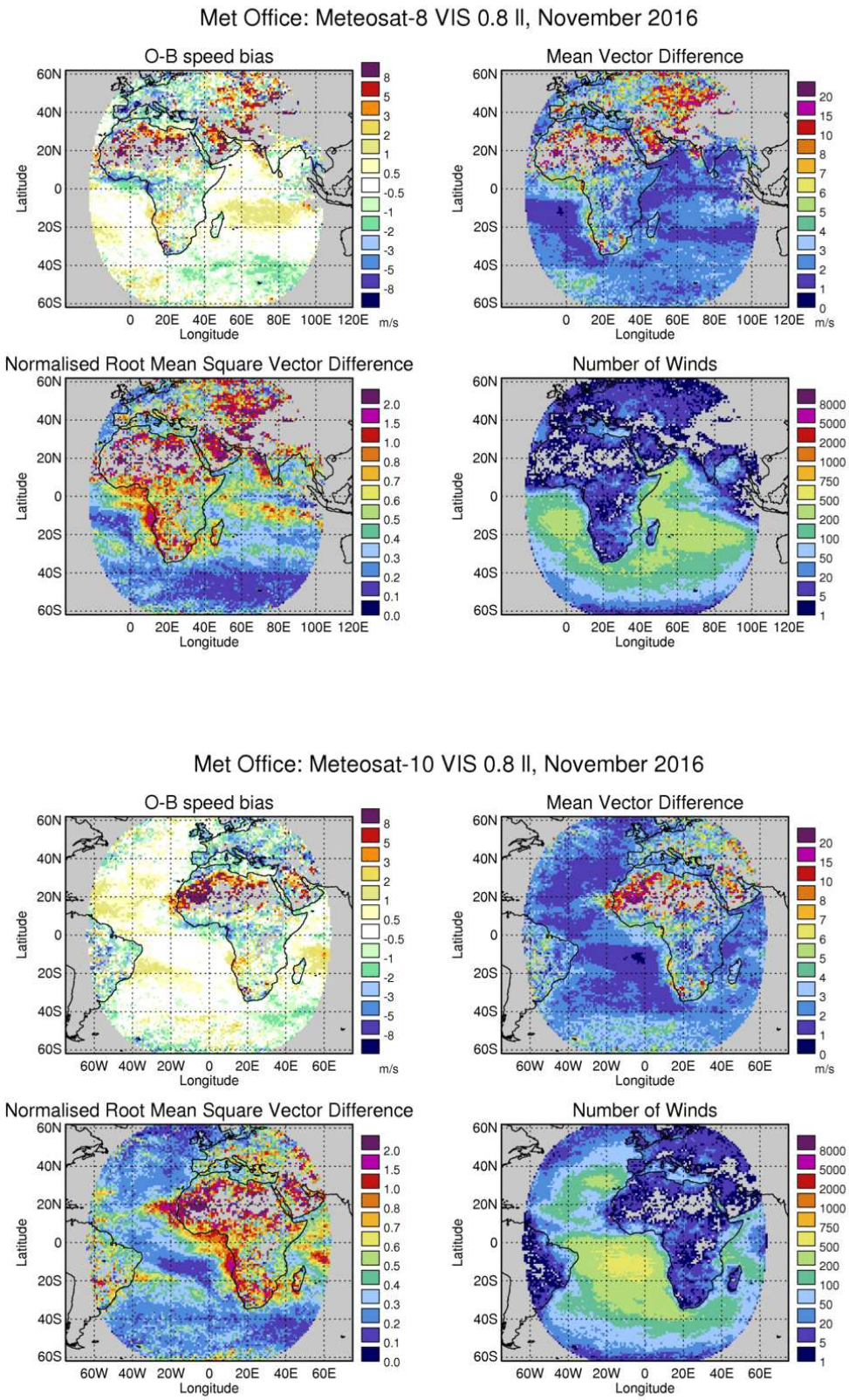
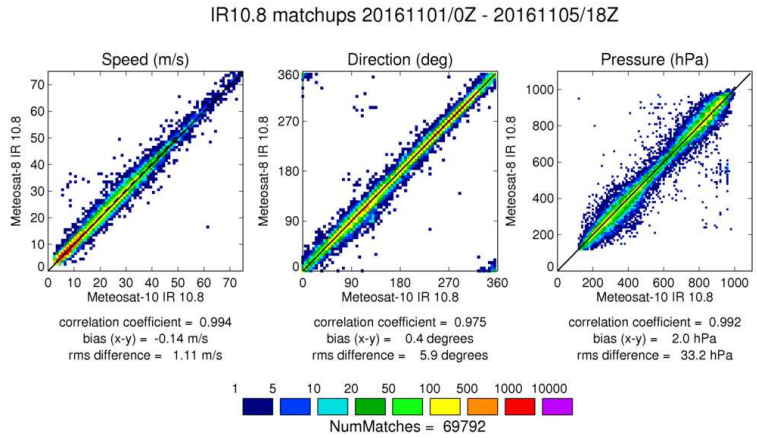


Figure 6: As Figure 5 but for visible 0.8 channel AMVs.

4. Collocations

As Meteosat-8 and Meteosat-10 overlap over a wide area we can quickly build up a large number of matchups in space and time. Figure 7 shows collocated Meteosat-8 and Meteosat-10 AMVs for the first 5 days of November 2016. The matchup criteria are observations within 10 mins (i.e. restricting to data with same validity time) and 10-km. The IR, WV7.3 μm, and visible 0.8 μm (not shown) channels all show excellent vector and height agreement. For the HRVIS channel (Figure 7c), although the vector agreement is very good there is a bias in the assigned heights with Meteosat-8 on average 13 hPa lower in height than Meteosat-10. The root mean square (RMS) height difference for HRVIS is ~ 42 hPa compared to ~ 24 hPa for the visible 0.8 μm. The reason for the difference in HRVIS heights is unclear.

a)



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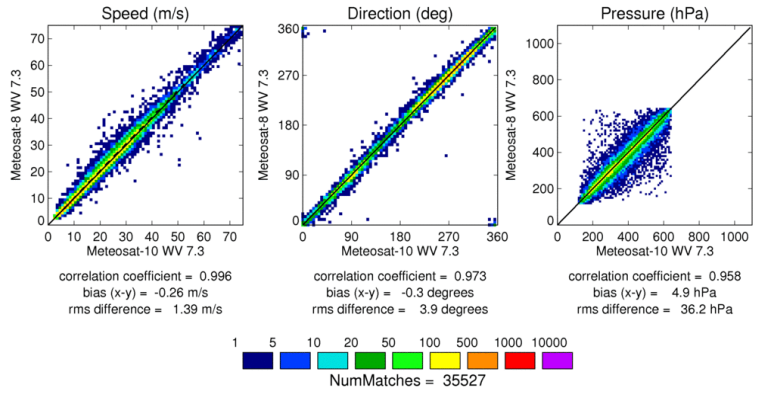

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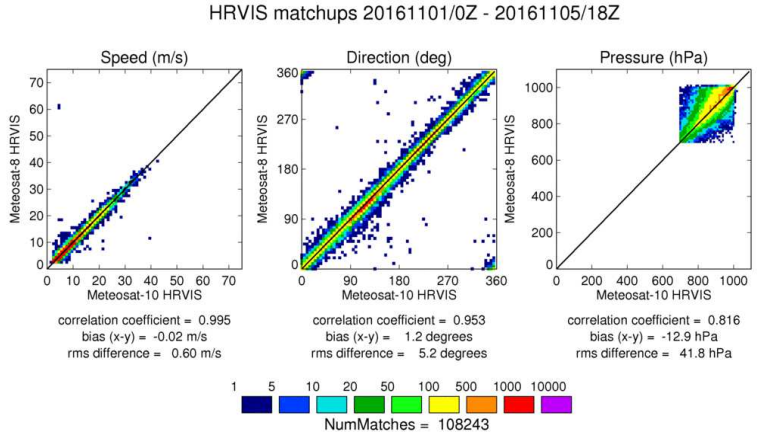

Figure 7: Comparison of wind speed, wind direction and assigned pressure for collocated Meteosat-8 and Meteosat-10 AMVs for the period 1-5 November 2016. AMVs matchups are within 10-km. Channels shown are a) IR10.8, b) cloudy WV7.3, and c) high resolution visible.

5. Impact Experiments

Assimilation experiments were performed for the two-month period from 1 November 2016 to 31 December 2016. The PS38 experiment baseline included variational bias correction (VarBC) for satellite radiances, hybrid 4D-Var, N108/N216 VAR and N320/L70 UM forecasts. A reference suite was created to assimilate all data, but with no IODC AMVs (note that Meteosat-7 radiances were assimilated). Two experiments were then performed to evaluate the impact of adding Meteosat-7 or Meteosat-8 AMVs on top of the 'no IODC AMV' baseline. Meteosat-8 AMVs were assimilated in exactly the same way as for Meteosat-10, using the same height error profiles and quality control (see NWP SAF page http://nwpsaf.eu/monitoring/amv/amvusage/ukmodel.html).

NWP Index scores for these comparisons are shown in Table 4. For a 60-day trial any impact score of less than ~0.3% can be considered neutral at the 95% significance level (Weston, 2014). Whilst index scores for both experiments are neutral overall, it is evident that Meteosat-8 is more on the positive side having scores of +0.1 against observations and +0.2 against analyses. The fit of the background (T+6) forecast to the AMV observations used in each experiment are shown in Table 5. Replacing Meteosat-7 with Meteosat-8 leads to nearly 2000 additional AMVs assimilated and small improvements to the standard deviation fit of the U and V winds (over 1% reduction for meridional wind). Changes in the fit to other observations types are generally less than 0.3%, e.g. Scatterometer 10-m winds component fits reduced by 0.15%, AIRS/IASI reduced up to 0.3%, CrIS temperature sounding channels reduced up to 0.3% but humidity sounding increased by up to 0.15%.

Experiment	Reference	Days	Observations	Analysis	ECMWF
u-ai603 Met-7 AMV	u-ai606 No IODC AMV	59	+0.02 (0.02%)	+0.06 (0.04%)	+0.13 (0.10%
u-ai607 Met-8 AMV	u-ai606 No IODC AMV	59	+0.10 (0.09%)	+0.20 (0.15%)	+0.21 (0.17%)
u-ai607 Met-8 AMV	u-ai603 Met-7 AMV	59	+0.04 (0.04%)	+0.12 (0.09%)	+0.07 (0.06%)

Table 4: Comparison of NWP Index scores for the Meteosat-7 and Meteosat-8 experiments versus a 'no IODC AMV' baseline. The difference between the experiments is also shown.

Experiment	Mean AMV counts	U wind Stdv O-B m/s	V wind Stdv O-B m/s
u-ai603 / Met-7 AMV	48948	2.69	2.53
u-ai607 / Met-8 AMV	50927	2.67	2.50
u-ai607 – u-ai603	+1979 (4.0%)	-0.6%	-1.3%

Table 5: Standard deviation of the background forecast fit to the assimilated AMV observations for U and V component winds and the mean number of observations used in each experiment. The difference between Meteosat-7 and Meteosat-8 experiments is also shown.

The impact of assimilating Meteosat-7 and Meteosat-8 IODC AMVs on the mean wind analysis can be seen in Figure 8. Whilst both experiments tend to increase the strength of the south-easterly trade winds south of the equator in the Indian Ocean (Figure 8b), Meteosat-8 changes the analysis over a larger spatial area. At 250 hPa both satellites act to slow the mid-latitude jets. For Meteosat-8 the impact is limited to the region around 50-90°E (in the gap between Meteosat-10 and Himawari-8) but Meteosat-7 also changes the analysis where it overlaps with Metosat-10 over Africa and into the South Atlantic. This is despite Meteosat-8 being located further west and having greater temporal frequency. Where satellites overlap, AMVs within the same spatial-temporal thinning box are selected by the lowest observation error. Meteosat-7 having more of an impact on the analysis over Africa may be due to incorrect specification of observation errors relative to Meteosat-10, resulting in Meteosat-7 being given too much weight. The magnitude of the analysis difference is greatest for Meteosat-8 around 40°N (-0.8 m/s) whereas for Meteosat-7 it is greatest around 40°S (-0.6 m/s). Polewards directional changes in the jet regions are also noticeable.

Figure 9 and Figure 10 show the percentage change in forecast RMS error for the Meteosat-7 and Meteosat-8 experiments respectively. Meteosat-7 shows some small but significant (at the 95% level) increases in forecast error in the southern hemisphere. Small beneficial impacts are seen for the tropical 850 hPa winds (e.g. 0.7% reduction for T+12 against observations).

When Meteosat-8 is assimilated we find larger impacts on forecast errors which are mostly beneficial. Significant error reductions are seen for tropical winds at 850 hPa against own and ECMWF analyses at all lead times, and against observations (e.g. 1.2% reduction for T+12 against observations). Against analyses, winds at 250 hPa show smaller errors out to T+36 in the tropics which leads to improvements in the NH at longer lead times. Geopotential height errors at 500 hPa in the SH are reduced versus

ECMWF analyses (not significant) but not against own analyses. Some increases in RMS error are seen for SH winds at 250 hPa.

Figure 11 confirms that replacing Meteosat-7 with Meteosat-8 generally has a beneficial impact on reducing forecast errors. Small but significant error reductions are seen for tropical winds at both 250 hPa and 850 hPa (significant out to T+36). 500 hPa geopotential height errors are reduced in the SH, with changes significant for some lead times against observations (e.g. 2.0 % reduction at T+96).

850 hPa 250 hPa

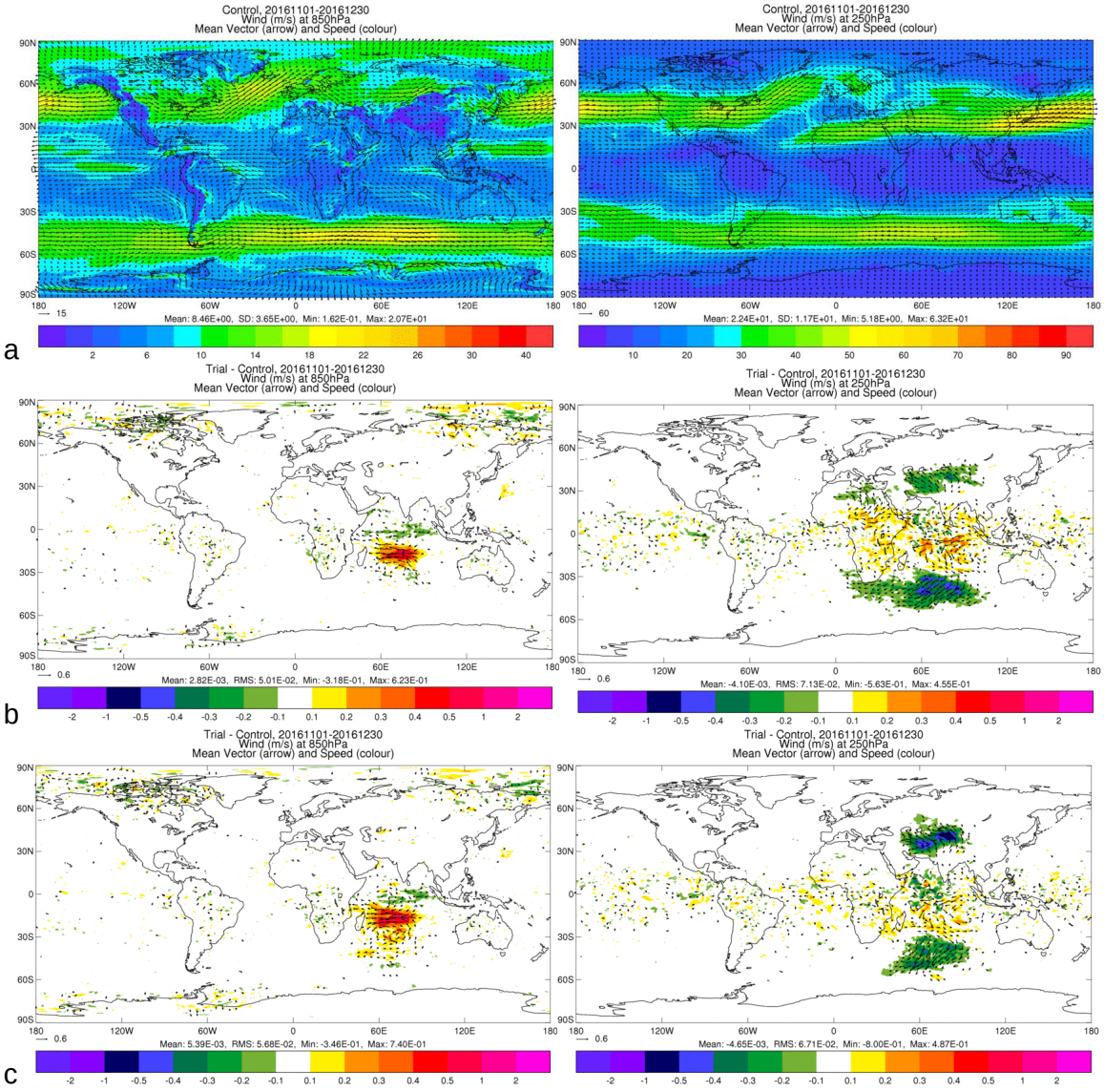

Figure 8: Mean analysis wind fields and analysis differences at 850 hPa (left) and 250 hPa (right). a) Mean wind analysis for the reference experiment. b) Mean vector and wind speed difference between the Meteosat-7 experiment and the reference. c) Mean vector and wind speed difference between the Meteosat-8 experiment and the reference. Fields are averaged over all analysis cycles.

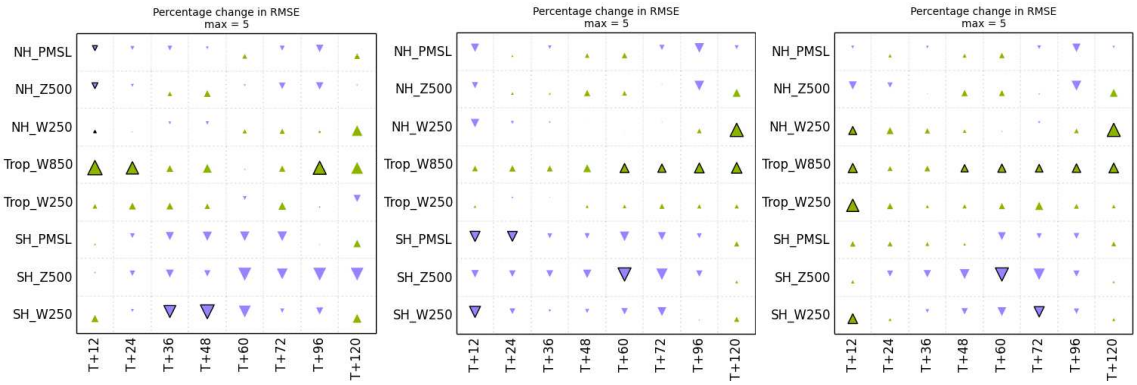

Figure 9: Change in RMS error for the Meteosat-7 experiment versus reference. Verification against observations (left), own analyses (centre), and independent ECMWF analyses (right). Green upward triangles indicate a positive impact (reduction in error) and blue downward triangles indicate a negative impact (increase in error). The size of the triangles is scaled to the size of the RMS change with a maximum of 5% filling the square box. Triangles with dark outlines show a significant impact at the 95% level (Wilcoxon signed-rank test)

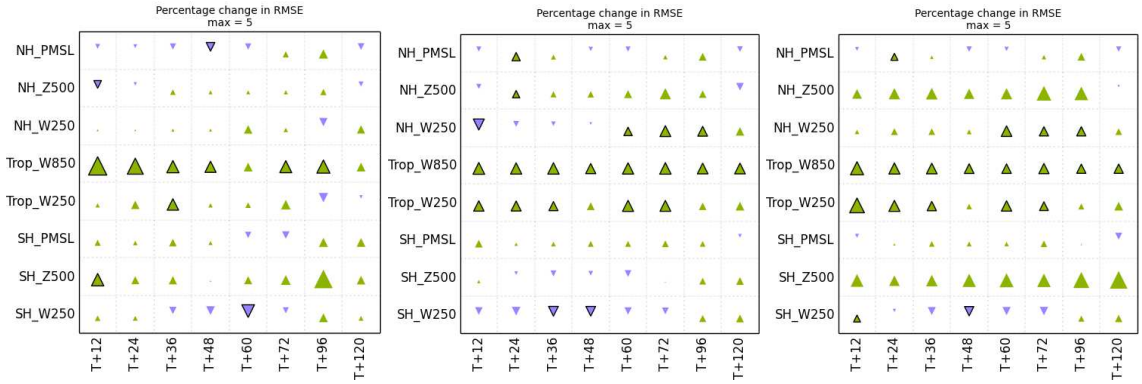

Figure 10: Same caption as for Figure 9 but for the Meteosat-8 experiment versus reference.

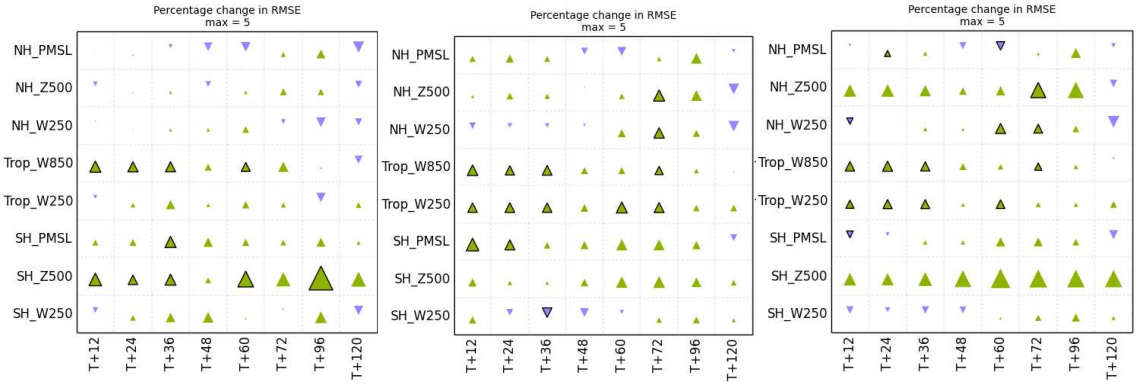

Figure 11: Same caption as for Figure 10 but for the Meteosat-8 experiment versus Meteosat-7.

Profiles of wind RMS forecast errors are shown in Figure 12, Figure 13, and Figure 14 for the NH, tropics and SH respectively. Forecasts are verified against own analyses for lead times of 48 and 72 hours. In the tropics Meteosat-8 (green line) reduces wind errors throughout the troposphere, peaking at around 200 hPa, whereas the assimilation of Meteosat-7 increases wind errors at 150 hPa. In the NH Meteosat-8 reduces errors at T+72 for the whole profile, peaking at high level around 200-300 hPa. In the SH the impact of Meteosat-8 assimilation is more mixed as wind errors are reduced at low level below 800 hPa, but increased at high level around 200-300 hPa.

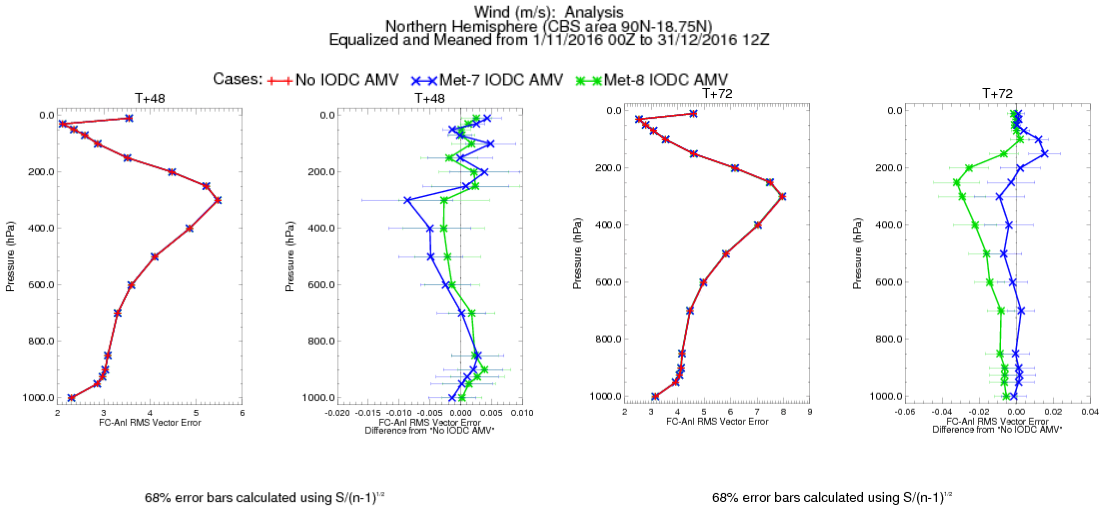

Figure 12: Wind profiles of RMS vector errors verified against own analyses: T+48 (left) and T+72 (right) forecasts in the northern hemisphere. The red line is the reference, the blue line is the Meteosat-7 experiment, and the green line is the Meteosat-8 experiment.

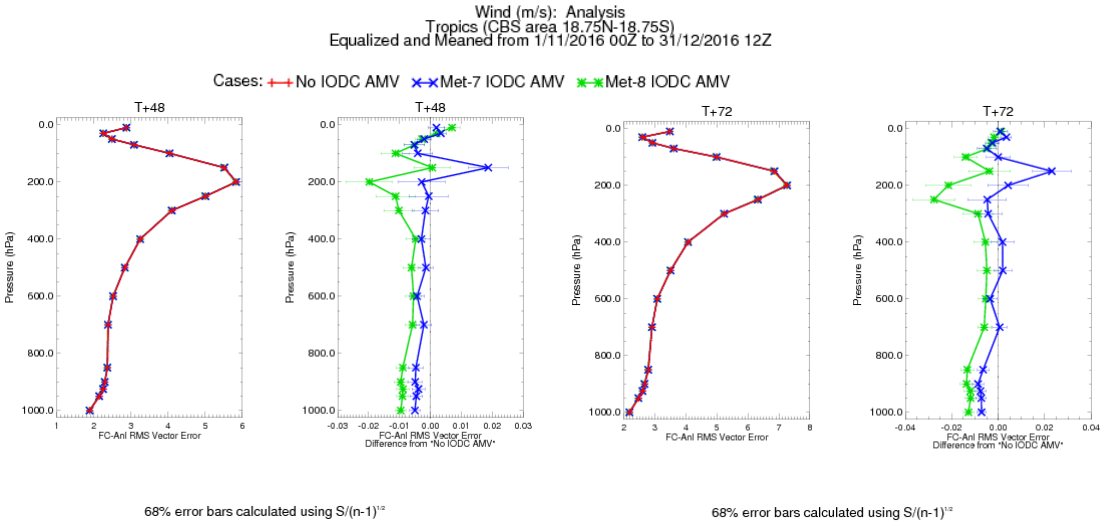

Figure 13: Same caption as for Figure 12 but for the tropics.

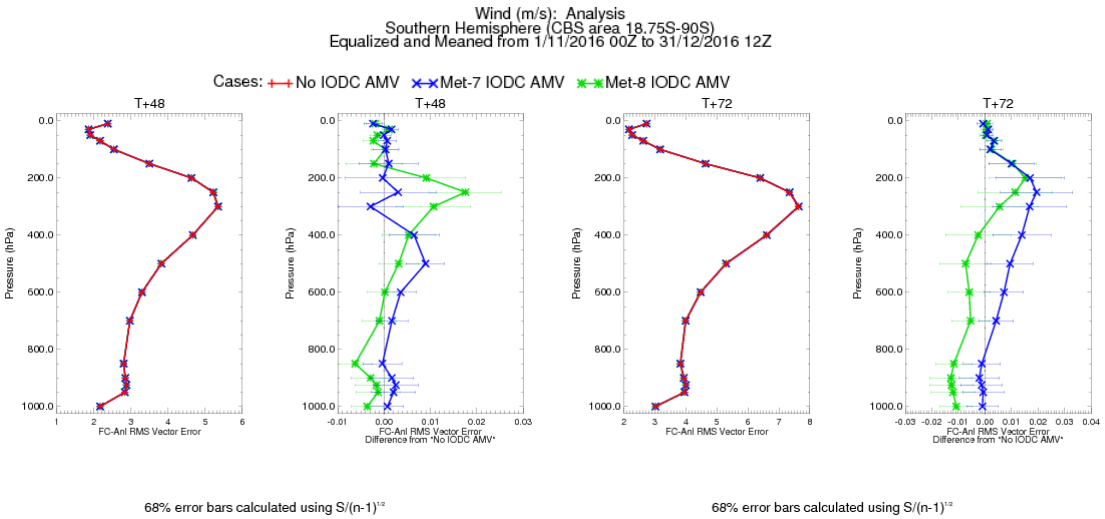

Figure 14: Same caption as for Figure 12 but for the southern hemisphere.

6. Conclusions and recommendations

In general the O-B departure statistics for Meteosat-8 are very similar to Meteosat-10 when compared over the coincident geographic area. For collocated observations, the vector and height agreement is very good. The HRVIS channel however has a small bias in the assigned heights with Meteosat-8 on average 13 hPa lower in height.

When we compare global statistics for the two MSG satellites the low level O-B speed departures appear worse for Meteosat-8 in the northern hemisphere. Here standard deviation O-B is up to 2x larger for the IR and visible channels below 700 hPa height and the IR channel has a larger positive bias. Map plots show that this is because Meteosat-8 covers more land surface in the northern hemisphere where low level AMV data quality is reduced. When we compare to Meteosat-7 it is clear that Meteosat-8 has smaller departures, including at low level.

Zonal plots show that Meteosat-8 IR AMVs have a positive speed bias and increased vector difference for data located around 15-30°N that extends from the surface to ~300 hPa. This bias is far more pronounced than for Meteosat-10. Maps show this is coming from an area east of 60°E over the Arabian Sea and North India which are not covered by Meteosat-10.

Replacing Meteosat-7 with Meteosat-8 leads to nearly 2000 additional AMVs assimilated and a small improvement in the fit of the AMVs to background (over 1% reduction for meridional wind). The current assimilation of Meteosat-7 leads to some significant

increases in forecast error in the southern hemisphere. When we assimilate Meteosat-8 instead the forecast impacts are generally improved relative to Meteosat-7. Small but significant error reductions are seen for the tropical winds at 850 hPa at all lead times against own and ECMWF analyses. Winds at 250 hPa show smaller errors at short-range in the tropics and at longer lead times in the NH. Geopotential height errors at 500 hPa in the SH are reduced versus ECMWF analyses (but not significant).

NWP index scores for Meteosat-8 are neutral but tending towards positive (+0.1 versus observations, +0.2 versus analyses). Overall the forecast impact of Meteosat-8 is encouraging, especially considering the large overlap with Meteosat-10.

The Meteosat-7 and Meteosat-8 experiments both show an increase in forecast RMS errors for high level winds in the southern hemisphere. Comparing differences in the mean wind analysis shows that the AMVs act to slow the jet stream in both hemispheres. Although biases for Meteosat-8 are improved relative to Meteosat-7, a negative speed bias remains at high level in the extra-tropics for the IR channel. In the southern hemisphere the AMVs may be having a negative impact due to the lack of other wind observations (e.g. aircraft reports) to constrain the analysis. For Meteosat-8 we also assimilate a greater number of AMVs in the SH jet region because of the blacklist in place for the Meteosat-7 IR channel.

As the first MSG satellite, Meteosat-8 offers numerous advantages over Meteosat-7 including improved AMV quality, more channels, and higher spatial and temporal resolution. Assimilation experiments show a beneficial impact on forecast errors for Meteosat-8, particularly for the tropical wind fields. **Therefore it is recommended that Meteosat-8 AMVs should replace Meteosat-7 in operations before Meteosat-7 reaches end of life.** The routine stationlist update scheduled for 21 February 2017 is the most appropriate implementation date for this change.

7. References

Weston, P. (2014). The statistical significance of assimilation trial results: case study on SA package trials for PS34. *Satellite Applications Technical Memo 22*.

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